Optimizing the Performance of Health Facilities in Egypt: Using a Hybrid Approach Combining Biophilic Design and BIM

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***Abstract*—Most of the health facilities in Egypt neglect the importance of human connection with the surrounding nature, which results in multiple physical, psychological, and emotional problems such as stress, lack of concentration, fatigue, and a decrease in performance. To overcome this problem, this paper suggests a hybrid approach combining Biophilic design and BIM. This approach combines both Biophilic design and BIM through a restorative environmental design concept to combine both environmental and human aspects. This study's results develop a checklist that assesses Biophilic design patterns that exist in buildings by analyzing the KTPH case example. In addition to exploring a framework for Building Information Modeling (BIM) to be used with sustainability assessment methods in buildings. The paper concludes with the importance of the human-nature relation and how to apply this approach in Egypt, in addition to theoretically combining Biophilic design and BIM.**

***Keywords*—restorative environmental design, biophilic design, healthcare facilities, sustainability, Building Information Modeling (BIM)**

I. Introduction

Humans have evolved to a great extent in natural not constructed or artificial world, which appears in their reliance on affiliating with nature. Developing the human mind and body is controlled by crucial environmental features such as light, sound, odor, wind, weather, water, vegetation, animals, and landscapes. The skills and aptitudes learned from the association with natural systems and processes affects emotions, problem-solving, critical thinking, and constructive abilities [1].

As a result of the age of information-known as the computer age-At the mid-20th century, and the rapid development in technology the gap between human and nature increased. Humans started to detach themselves from nature through architecture, which appears in all modern buildings that does not respect the context of their surroundings. As a result of human abuses, nature started to get its revenge against human [2].

This appears in the climate change, global warming, widespread diseases, and more. The modern design of built environment has caused a sustainable crisis as it focused only on one dimension of sustainability which is environment, and neglected all other dimensions which is economic and social dimension [2].

II. Restorative Environmental Design

Spending time outdoors or indoors with visual contact with nature is experimentally proven, which have restorative benefits than staying in urban environments, and this can promote physical and mental health in the long run. Human's health is affected on a personal basis is by restoration. By the regeneration or recovery of adaptive resources or abilities that have decreased while attempting to meet daily demands [3].

Nowadays sustainable design is well recognized an aim for all counties because of all the environmental changes.

There are many sustainability assessment methods that are used to facilitate the process of designing sustainable buildings such as, LEED in The United States, BREEAM in the UK. The problem is that these methods are all inclusive, ignoring human importance to interact with nature [4].

The built environment's traditional design has played a significant role in the issue. Wherefore, a new design concept appeared by Kellert known as Restorative environmental design which combines all dimensions of sustainability in design. As shown in Fig. 1, Restorative environmental design approach which combine both low-impact strategies that minimizes the impacts on natural environment and Biophilic design approach to increase contact of people with nature [5].

A. Biophilia

Biophilia is the design of built environment respecting human need to connect with natural systems and processes. Humans and nature affect each other. Biophilia is important in supporting psychological well-being, physical health, and increasing healing rates in healthcare facilities. Applications of Biophilic design can be found at several scales, including parks, streetscapes,

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urban design, and interior and architectural design. Recent researches demonstrate how Biophilic architecture and exposing people to natural settings can enhance their general health and wellbeing. For instance, numerous researches investigated and revealed various advantages of natural and Biophilic environments for psychological and cognitive health [6]. The role of Biophilic design is to restore the relation-ship between man and nature so that man can benefit from all the advantages of his communication with it.

Biophilic design was recognized by some landscape architects that it embraces more than traditional landscape architecture or just incorporating building-integrated vegetation as well as natural spaces, patterns, and materials into building design [7].

The concepts of Biophilic design have been introduced in a book called Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life. The book outlined the origins of Biophilic design and defined a new way of thinking and designing for urban inhabitants by outlining an alternative human–nature connection. The book's theory, research, and design aspects are all focused on the human–nature connection and the social advantages it provides [1].

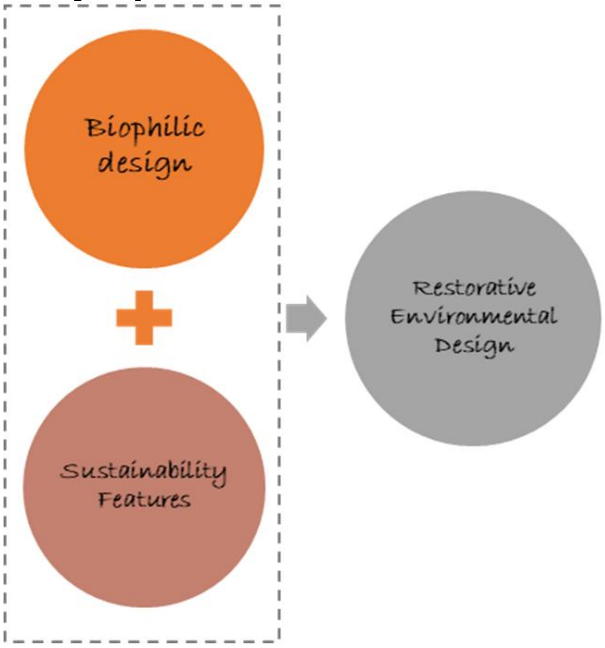

Figure 1. Restorative environmental design.

B. *Patterns of Biophilic Design*

Christopher Alexander, Judith H. Heerwagen, Rachel and Stephen Kaplan, Stephen R. Kellert, Roger Ulrich, and others have all contributed to the discussion of Biophilic design for health and wellness. William D. Browning and Catherine O. Ryan pioneered the synthesis and translation of the research into a digestible list of design patterns, which provided thorough yet flexible direction for site-appropriate implementation [8]. Which resulted in 14 pat-terns of Biophilic design included in three categories. Nature in the Space include; Visual Connection with Nature, on-Visual Connection with Nature, Non-Rhythmic Sensory Stimuli, Thermal & Airflow Variability, Presence of Water, Dynamic & Diffuse Light, and Connection with Natural Systems. Natural Analogues include; Biomorphic Forms & Patterns, Material Connection with Nature, and Complexity, & Order. Nature of the Space include; Prospect, Refuge, Mystery, and Risk/Peril [9].

C. *Biophilic Design in Healthcare Facilities*

Since the second half of the 20th century, the design direction of Healthcare facilities modified considerably. Healthcare facilities are no longer seen as "Function" only but also as an "Experience." This enriched the concept of "Humanization" of hospitals which takes into account the users in the design process [2].

Applying the principles of Biophilic design has multiple physiological and psychological impacts which have been introduced by Browning in 14 Patterns of Biophilic Design. These principles can be applied to users of healthcare facilities. Applying Biophilic de-sign principles in the design of healthcare facilities benefit all users of health facility, enhancing the patient experience of treatment which leads to enhancing population health, in addition to the experience and well-being of the healthcare team. Browning divided the effects of Biophilic design into three levels; stress reduction, cognitive performance and emotion, and mood enhancement [2, 9].

D. *BIM*

Building Information Modeling (BIM) is one of the recent developments in the fields of architecture, construction, and management. It is considered a life saver for engineers in complicated projects, as it has the ability to detect errors in the design phase. BIM has no specific definition [10].

BIM is used as a design application in which information and documentation flow from and are acquired from the process, from conceptual design to construction and then to facility management. Moreover, using BIM technology, a produces an exact virtual model of a structure may be created digitally, and once the structure is finished, all of the necessary data and correct geometry to assist the project's construction, fabrication, and procurement processes will be available.

E. *Green BIM*

Sustainability is the ultimate use of natural resources while maintaining low costs of production and operation, without affecting the share of the future generations in natural resources. The construction sector is the biggest suspect in the emission of greenhouse gases, which is considered an ultimate problem facing environment, as only the production of cement produces 5% of global CO_2 emissions according to the World Business Council for Sustainable Development (WBCSD).

According to Gandhi and Jupp, BIM acts as a tool to enhance environmental certification standards for structures, infrastructures, or communities.

Green BIM is divided into three main pillars as shown in Fig. 2 [11]:

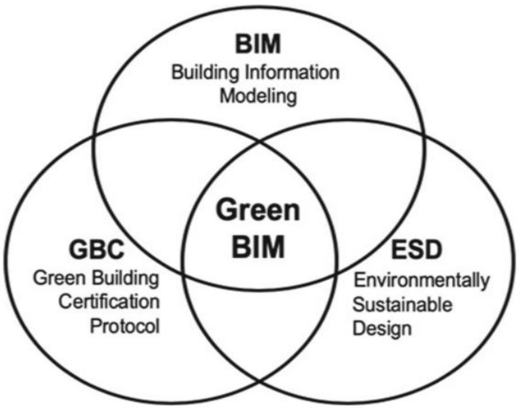

Figure 2. Three pillars of green BIM.

- Environmentally sustainable design (ESD) principles;
- improving building according to assessment method chosen in order to get credits Green Building Certification (GBC);
- Using BIM TOOLS through integrating all building systems

A building is considered sustainable, whenever it achieves sustainability in all its lifetime; design, construction, rehabilitation, and decommissioning. This is de-fined as Life Cycle Assessment (LCA) [12].

The capability of merging BIM and sustainable design has been an interest recently.

Green BIM refers to "The use of BIM tools to help achieve sustainability and/or improving building performance objectives on a project" according to the Smart Market report in 2010. BIM could be used as a tool for sustainability.

One of the essential uses of BIM is the integration with Building Sustainability assessment (BSA) in the design process. [13]

F. Sustainability Assessment Methods

Building Sustainability Assessment (BSA) has been introduced recently to analyze and evaluate buildings' sustainability through various considerations. It is a mean to help architects and designers to define the principles of "Selective Environmental design," which regard buildings as a "complex system" of various linked connections including spaces, users, materials, components, and energy. Using BSA contributes in increasing architects' and designers' responsibility toward environment, thus participating in designing more sustainable buildings [14].

There are various assessment tools available in construction world; Eco-Quantum (Netherlands), Eco Effect (Sweden), ENVEST (U.K.), BEES (U.S.), ATHENA (Canada) and LCA House (Finland) [15].

In UK BREEAM (Building Research Establishment Environmental Assessment Method), The United States LEED (Leadership in Energy and Environmental Design), and SBTool (Sustainable Built Environment) are considered the basis of other methods of assessment [13].

TABLE I. SUSTAINABILITY ASSESSMENT METHODS

	BREEAM	LEED	GPRS	TARSHEED
Date	1990	1998	2009	2015
Origin	United Kingdom	United States	Egypt	Egypt
Rating System	Weight system	Point System	Weight system	————
Catego-ries	Energy, Health and Wellbeing, Innovation, Land Use, Materials, Management, Pollution, Transport, Waste and Water	Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality and Innovation in Design.	water efficiency, Energy efficiency, sustainable sites, materials and resources, management protocols, indoor environmental quality, and innovation and added value	energy, water, habitat
Building Types	————	residential, hospitals, retail, schools and warehouses	————	Residential, Commercial, Communities, School, and Healthcare

Table I shows most known assessment tools internationally such as BREEAM and LEED, and assessment tools in Egypt such as GPRS (Green Pyramid Rating System) and TARSHEED.

Jalaei and Jrade proposed a methodology to combine BIM with LEED. As shown in Fig. 3, the methodology shows how model is implemented to calculate LEED points automatically, and all costs for sustainable materials to be used in design phase [16].

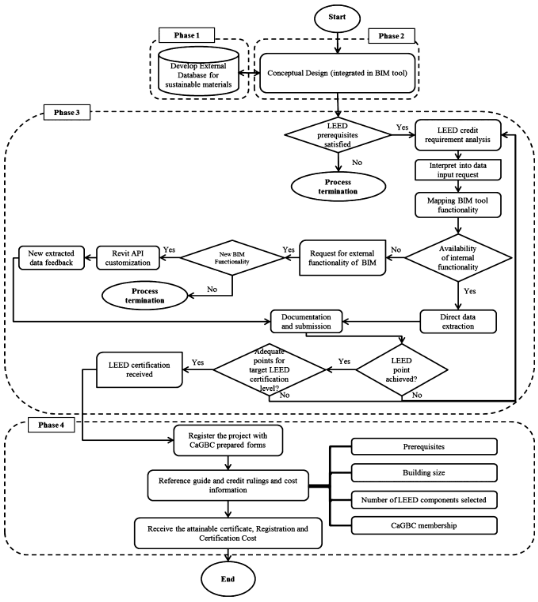

Figure 3. Flow chart of the integration process.

The process of integrating both BIM and LEED goes through four stages:

Stage 1 is designing the database of the model to be designed. This step has two levels, the first is "conceptual modeling" and the second is" the physical implementation."

All data is collected in an external file in extension of RVT (Revit) to input in BIM.

Stage 2 is related to BIM. This is the stage where the 3D model is designed to accept all data formed in stage 1.

Stage 3 is to develop the module used for green building assessment. All LEED components with the points are all installed to assess all materials used in model.

Stage 4 is related to calculate the registration costs through CaGBC (Canada Green Building Council) and certification costs.

III. CASE STUDY: KHOO TECK PUAT HOSPITAL

Khoo Teck Puat Hospital as shown in Fig. 4 (KTPH) sets a new bench-mark in healthcare design with its hospital in a garden, garden in a hospital' concept.

Figure 4. Khoo Teck Puat hospital.

A competition-winning scheme, it features sleek aesthetics and distinct façades for each of its three blocks."

KTPH is a public hospital in YISHUN with 795 beds serving more than 550000 people in north Singapore. As shown in Fig. 4, the hospital opens up to its adjacent lake, while a massive sunken courtyard takes center stage, introducing light and greenery to the lower levels.

Khoo Teck Puat hospital design depended on 3 pillars; a healthy community, sustainable development, and a healthy workforce. The idea was to achieve 4 goals which are:

- Building and purchasing green through the de-sign of the responsive façade respecting sustainability
- Conserving resources through design and energy-efficient systems and usage of renewable energy.

A. *Patterns of Biophilic Design Appears through the Design of KTPH. [17]*

1) *Visual connection with nature*

The ability of users to vision natural views and living systems while experiencing the connection with nature. Interacting with nature has multiple psychological and physiological effects.

- The aim is to create an environment that encourages people to shift their focus, relax their eye muscles, and reduce cognitive fatigue. [9] Khoo Teck Puat hospital design managed to achieve this aim by making the hospital a healing garden. Nature is visually and physically accessible, as shown in Fig. 5.

Figure 5. KTPH vegetation

2) *Non-visual connection with nature-non-rhythmic sensory stimuli-presence of water*

Figure 6. KTPH waterfall

The presence of water feature in space com-bines multiple patterns; visual connection with nature, on-visual connection with nature, and non-rhythmic stimuli. Khoo teck puat waterfall achieves all of previous patterns. As shown in Fig. 6, non-visual connection with nature and Non-Rhythmic sensory stimuli appear through the bur-bling sound made by waterfall. In addition to the smell of plants movement of fish inside pond, simulate what happens in nature.

3) *Thermal and air flow variability*

As shown in Fig. 7, Khoo teck puat is divided into 3 zones; Air-conditioned wards, naturally ventilated wards, and specialist clinics. Naturally ventilated wards complied with the environmental design criteria through the distribution of daylight. Windows in Air-conditioned wards are openable and deactivate the air condition system once opened.

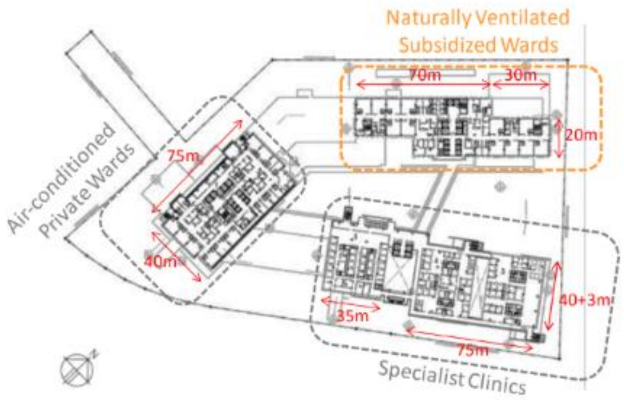

Figure 7. KTPH internal ventilation zones.

4) Dynamic and diffuse light

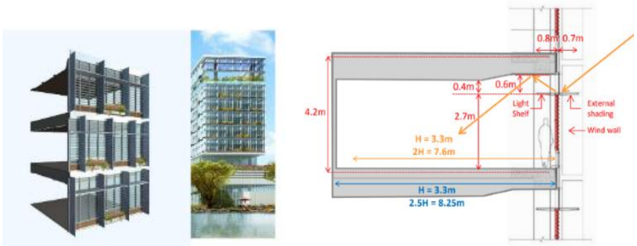

Figure 8. KTPH Facade treatment.

The Dynamic and Diffuse Light pattern has two goals: to provide users with lighting options that stimulate the eye and hold attention in a way that elicits a positive psychological or physiological response and to provide users with lighting options that stimulate the eye and hold attention in a way that elicits a positive psychological or physiological response. As shown in fig.8, design of façade permits maximum daylight in rooms.

5) Connection with natural systems

Figure 9. KTPH Roof garden.

Connection with natural systems is crucial to human well-being and development. Adaptive interaction with nature affects humans in all life phases, however, child-hood is the most effective phase as it is the development period of humans [1]. As shown in Fig. 9, KTPH turned roof into a garden when a group of farmers were displaced from their community farm plots.

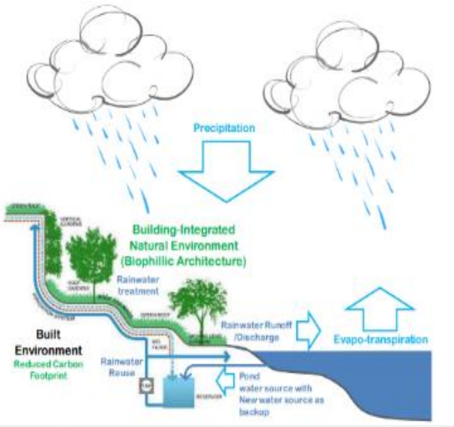

Figure 10. KTPH Water management.

To facilitate the work in gardens, architects pro-vided stairs and lifts to transport soil, materials, tools, and people.

KTPH management turned the rooftop into a garden. This turned the rooftop into a simulating ecosystem having species of dragonflies, fish, and butterfly. [18]

As shown in Fig. 10, pond is used to irrigate gardens from reusing rainwater.

B. Sustainability in KTPH

Sustainable applications in KTPH were achieved through the design of the responsive façade which respected sustainability and conserved resources through design and energy efficient systems and usage of renewable energy. [19]

1) Façade system that is responsive to climate change

As shown in Fig. 11, applying passive design to the facades of the building to react with the sun and wind movement. This minimizes the heat radiation and enhances natural lighting. Wing walls are used to direct wind into the building.

Figure 11. KTPH facade design.

2) Natural lighting

Exposure to natural lighting has multiple effects on healing and performance rate. 70% of wards and 60% of the gross floor of the hospital are lighted by natural lighting. In addition to using skylight, as shown in Fig. 12, which is used to light the basement thus reducing electricity consumption.

Figure 12. KTPH skylight for natural daylight.

Figure 13. KTPH Solar panels installed.

Figure 14. KTPH Sensors in parking and stairs.

3) Solar energy

In order to decrease the carbon footprint of the hospital, KTPH management decided to use solar panels, as shown in Fig. 13 which Produce 115 MWh annually. In the future, the hospital is planning to install floating solar panels over the Yishun pond.

4) Energy efficiency

Energy efficiency is shown in the usage of sensors in stairs and in the car parking, as shown in Fig. 14.

5) Water efficiency

Using water-efficient fixtures in the hospital resulted in saving 39.8% of the water consumption. As well as using Yishun pond to irrigate green areas in the hospital, as shown in Fig. 15.

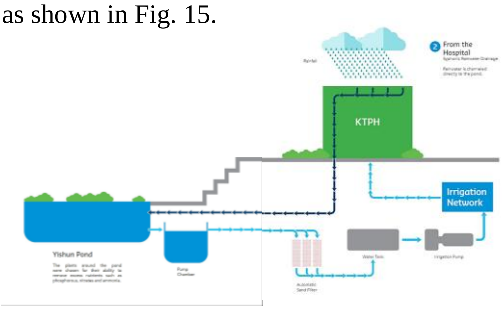

Figure 15. KTPH rainwater collection

Collecting rainwater and return to Yishun pond with sensors that stop irrigation systems in gardens when it rains.

IV. Discussion

As a result of analysis, there are multiple guidelines included for designers to follow in design process. These guidelines could be summarized in a checklist to be used in measuring existence of Biophilic design in buildings.

TABLE II. Biophilic Design Checklist

Biophilic design checklist		Yes or No	%
Visual Connection with Nature	Direct connection with nature		
	Visual link in space that can be used for at least 5 to 20 minutes per day.		
	Design spatial layouts and furnishings that maintain visual access while being in a seated position.		
Non-Visual Connection with Nature	Sources of natural sounds in built environment as water sound in fountains, smells of flowers, or breeze of air through natural ventilation.		
	Non-visual connection with nature in different locations that can be accessed easily including; Sound, Textures, Aromas)		
Non-Rhythmic sensory stimuli	Non-rhythmic stimuli every 20 minutes, for at least 20 sec, and from a distance more than 20 ft. such as water bubbling, breeze, sound of birds.		
	Technological interventions that simulate seasonal nature changing.		
Thermal and Air Flow variability	Materials, lighting, fenestration, and mechanical ventilation to Improve space thermal conditions.		
	Thermal and air flow variability well studied in design process according to context of building.		
Presence of Water	Presence of water feature in built environment such as fountains.		
	Presence of water feature in space such as water wall, ponds, or water fall.		
Dynamic and Diffuse light	Direct sunlight inside space.		
	Dynamic light in design that is used to transit between indoor and outdoor.		
	Lighting feature that is suitable for space and function.		
Connection with natural systems	Use natural systems in design as in rainwater infrastructure used in landscape		
	Visual access to natural systems or use of interactive materials that change when exposed to solar heat, wind, or moisture.		
	Design interactive spaces for children, patients, and elders		

The checklist as shown in Table II, measures if Biophilic patterns exist or not, it will be answered with yes or no. Then there will be a percentage given, over 50% is acceptable and less than 50% is rejected.

Following up Jalaei and Jrade methodology, and by adding Biophilic design patterns at first phase, the merging between Biophilic design and BIM could be applicable. This is shown in Fig. 16, which discusses the hybrid approach combining Biophilic design and BIM. Through the pre-design and design phase, Biophilic design could be added in preliminary stages as an input to design process, in addition to sustainable building materials and applications. Then design is translated into data to be put in BIM then Revit. Revit is the program that will be used to be installed in Green Building studio to perform building performance simulation. Green Building studio supports LEED glazing points.

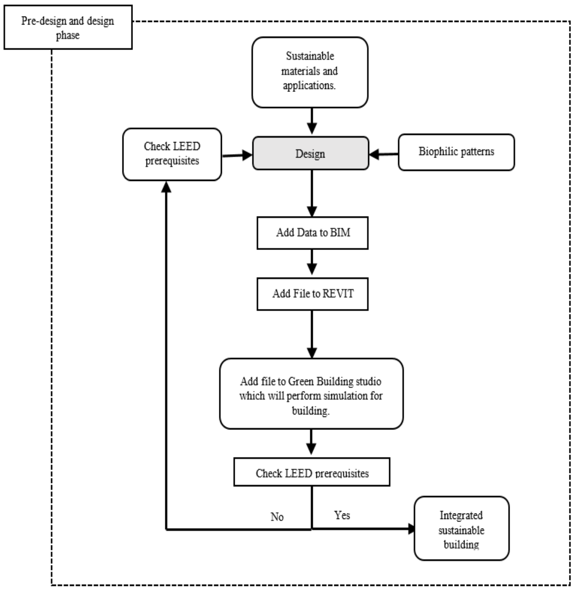

Figure 16. Hybrid approach of biophilic design and BIM

Through performance output data, a second LEED checklist is done to assess if building is LEED certified or not. If score is sufficient for building to be certified, then building would be an integrated sustainable building from all dimensions; environmentally, economically, and socially. Oppositely, all steps will be redone to check LEED prerequisites to be modified.

V. Conclusion

Applying Biophilic design principles improves the work environment in health facilities, and it would be a great advantage to apply these principles in Egypt. Biophilic design has been used in multiple projects worldwide and has proved its effectiveness. Yet it has not been presented in Egypt. Through the analysis of Biophilic principles in KTPH, it is clear that applying Biophilic principles leads to further thinking of sustainable applications in building. Thus, Biophilic design leads to increasing awareness towards the environment, achieving both reconnections with nature and a decreasing impact of buildings on the environment. Biophilic principles applied in KTPH could be applied in health facilities in Egypt through following the suggested checklist conduct with considerations to the climate, surrounding context, available materials, and type of vegetation suitable.

Further research would be conducted to test the use of Biophilic design and BIM in measuring building performance through the GREEN Building studio.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Rowan Hany conducted and wrote this paper under the supervision of Professor Hassan Abdel Salam and Professor Ali Bakr. All authors had approved the final version.

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